Remote-Site Ambient Ozone Data Summary, 2021

Regions 2 and 4, US Forest Service

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SNOTEL housing the Snowbird ozone monitoring site, Wasatch NF, UT.

Executive Summary:

- The Colorado Front Range and Utah's Wasatch Front and Uintah Basin remain in nonattainment of the ozone NAAQS. The Front Range nonattainment area was expanded to include all of Weld County, Colorado, and two of the RMRS network's sites (Briggsdale and Pawnee Buttes) are now within the area's boundaries.
- Network-wide, ozone was down somewhat from 2020, when large wildland fires produced extreme levels of surface ozone. However, long-duration high-ozone events occurred in midsummer of 2021 which resulted in unusually high exposure metrics being measured at a number of sites. Greatest exposure was noted at high-elevation Front Range sites and at low elevation on the Pawnee National Grassland. High exposure metrics were also observed at sites within Utah's nonattainment areas.
- The most significant ozone events occurred, unusually, in the summer months. In most years, ozone has peaked at most high-elevation sites much earlier in the year. This puts potential impacts of this pollutant in the middle of the alpine/subalpine growing season.
- Ozone remains at non-hazardous levels in much of the network's southwestern footprint.
- A new site, Hebron Slough in North Park, Colorado, was established and will assess surface ozone in a significant oil and gas development area.

I. Changes in the Regulatory Environment

USEPA made a significant change to their adjudication of the Denver/North Front Range ozone nonattainment area in late 2021. The District of Columbia circuit court ruled that all of Weld County be included in the nonattainment area (USEPA 2021), whereas previously only the southern part of the county had been within the area's boundary. This is significant for the RMRS ozone monitoring network as the nonattainment area now includes the two sites on the Pawnee National Grassland: Briggsdale and Pawnee Buttes. Both stations recorded high levels of ozone in 2021.

As of the end of 2021, the northern Colorado/Denver metropolitan ozone nonattainment area remained in "moderate" ozone nonattainment status. However, USEPA have proposed that the Denver nonattainment area be upgraded (or downgraded, depending on one's perspective) to "serious" nonattainment (USEPA 2019). The 2016 moderate designation resulted in state-level efforts to mitigate surface ozone pollution, but these have not been effective. USEPA set a July 2021 deadline for meeting the ozone NAAQS, and this deadline was not met. Changes to the state's implementation plan (SIP) are ongoing, and the state has also submitted a request ("demonstration") for allowances to be made for the severe wildfire seasons of 2018-2020.

The Salt Lake City/Wasatch Front and Uintah Basin nonattainment area remains in "moderate" status with mitigation efforts ongoing.

II. Network Performance, Changes and Updates for 2021 (Table 1 below)

One new site was established in 2021, at Hebron Slough on the Arapaho National Wildlife Refuge. This site is a year-round data collection site and is located about 40 km south of Walden, Colorado, in Jackson County. The area has experienced considerable oil and gas development in the past 10 years, and this site is proximate to several O&G wells and storage/transmission facilities.

No sites were decommissioned in 2021.

The Douglas Pass site experienced considerable wind damage over the winter and was reconstructed and reinforced in spring of 2021. Strong, continuous southwesterly winds accelerate up this pass and create near-arctic conditions at the site despite the relatively low elevation, especially in springtime. The new reinforcement should be sufficient to tolerate the conditions.

Network-wide, data completeness was 85.6%, and 84.3% at USFS-managed sites. Three sites experienced malfunctions that significantly affected data completeness:

The Grand Mesa site continued to be plagued by unexplained instrument malfunctions, with extreme calibration drift of the analyzer and apparent contamination or leakage in the inlet path. The inlet tubing and filter fittings were replaced in autumn 2021, the site's power controller was replaced, and new instrumentation was installed.

Road conditions in Bear's Ears National Monument precluded instrument recovery in fall of 2021, so the site continued operating all winter. Unfortunately, this resulted in much of 2021's data being overwritten by the datalogger, and only 12% of the data were recoverable, all from late in the season.

The storage battery at Kremmling lost capacity over the winter and the site was able to operate only during daytime for most of the season. However, data were sufficient to fully assess ozone at the site.

The network began transition to long-life (cartridge) inlet filters in 2021, with four sites selected for beta testing. These filters eliminate the need for monthly filter media changes and reduce the likelihood of inlet path contamination and ambient air leakage during calibrations. They also reduce operator workload and enhance the network's ability to collect data at very remote sites (e.g., Dark Canyon, Ruby Guard) where access is difficult. Post-season evaluation of the filters indicates that they adequately remove particulates from sample air, and do not break down ozone in any significant amount if they are pre-conditioned in the lab before deployment.

At three sites (Grand Mesa, Ripple Creek Pass, Deadman), early-season access is usually restricted by snow or adverse road conditions. These sites have been programmed to start up unattended in the spring and begin data collection. Operators will visit the sites as soon as is practicable, usually in June.

Year-Round Sites	Forest	Begin Date	End Date	Data Completeness	Notes
Pawnee Buttes	PNG	1 Jan	31 Dec	88.3	
Briggsdale	PNG	1 Jan	31 Dec	98.2	
Kenosha Pass	PSINF	1 Jan	31 Dec	88.2	
Sunlight Mountain	WRNF	1 Jan	31 Dec	99.0	
Little Mountain	Ashley	1 Jan	31 Dec	94.6	
Hebron Slough	FWS	1 Jan	31 Dec	88.5	
Centennial CASTNet	MBRNF	1 Jan	31 Dec	94.9	
RMNP CASTNet	RMNP	1 Jan	31 Dec	94.3	
Gothic CASTNet	GMUG	1 Jan	31 Dec	91.3	
Dinosaur NM CASTNet	NPS	1 Jan	31 Dec	96.3	
Shamrock	SNJF	1 Jan	31 Dec	92.4	
Mesa Verde CASTNet	NPS	1 Jan	31 Dec	94.5	
Canyonlands CASTNet	NPS	1 Jan	31 Dec	98.9	
GBNP CASTNet	NPS	1 Jan	31 Dec	98.5	
Seasonal Sites					
Deadman Pass	ARNF	4 Apr	6 Nov	73.2	
Goliath Pk	ARNF	27 May	27 Aug	71.3	

Trout Cr Pass	PSINF	29 Apr	4 Oct	72.2	
Kremmling	BLM	6 May	1 Dec	49.2	Power issue, no overnight data
McClure Pass	GMUG	5 May	29 Sep	97.2	
Ripple Cr Pass	WRNF	29 May	29 Sep	96.0	
Grand Mesa	GMUG	4 May	11 Jul	37.1	Multiple equipment failures
Norwood	SJNF	26 Mar	3 Oct	98.7	
Douglas Pass	BLM	3 May	30 Sep	76.4	
Snowbird	WCNF	3 May	1 Oct	98.9	
Dark Canyon	MLSNF	30 Apr	2 Oct	12.0	Multiple equipment failures
Ruby Guard	HTNF	2 May	1 Oct	99.1	

Table 1. 2021 Network performance

II. Data Summary:

	Average O_3 (ppb)		Daily 8-hour O_3 (ppb)				Cumulative O_3 (ppm-hr)	
Year-Round Sites	**Daytime**	**Overnight**	**Max**	**Date**	**4th Max**	**Date**	**Max W126**	**Period**
Pawnee Buttes	47.9	40.6	80.0	22 Jul	79.5	19 Jul	27.9**	Jun-Aug
Briggsdale	43.5	20.8	83.0	19 Jul	78.2	22 Jul	24.6**	Jun-Aug
Kenosha Pass	49.8	48.5	82.2	19 Jul	76.5	18 Jul	15.4	Jul-Sep
Sunlight Mountain	48.5	48.3	73.3	8 Aug	68.7	11 Aug	9.6	Jul-Sep
Little Mountain	51.2	50.7	89.9	8 Aug	76.7	29 Aug	26.1**	Jul-Sep
Hebron Slough	47.1	29.2	74.4	24 Jul	71.6	11 Aug	10.4*	May-Jul
Centennial CASTNet	48.8	48.5	77.4	27 Jul	72.1	9 Aug	16.1	Jul-Sep
RMNP CASTNet	49.8	45.9	83.0	27 Jul	77.8	19 Jul	20.3**	Jun-Aug
Gothic CASTNet	48.4	39.8	68.1	10 Jul	65.0	24 May	10.8	May-Jul
Dinosaur CASTNet	43.3	30.3	73.1	29 Aug	68.1	7 Aug	13.3	Jul-Sep
Shamrock	47.4	40.3	68.3	8 Jun	66.4	8 Aug	10.8	Jul-Sep
Mesa Verde CASTNet	47.5	45.6	75.3	7 Aug	67.8	9 Jun	13.1	May-Jul
Canyonlands CASTNet	45.6	44.1	75.9	8 Aug	69.1	11 Aug	13.2	Jun-Aug
GBNP CASTNet	46.1	43.7	80.9	6 Aug	68.6	9 Jul	12.6	Jun-Aug
Seasonal Sites								
Deadman Pass	58.5	62.1	89.5	27 Jul	83.3	4 Sep	25.3**	Jul-Sep
Goliath Pk	57.4	56.5	87.0	19 Jul	84.1	20 Jul	13.1*	Jul-Sep
Trout Cr Pass	55.0	49.7	76.1	19 Jul	72.8	18 Jul	16.2	Jul-Sep
Kremmling	49.3	33.4	75.8	19 Jul	67.7	10 Jul	10.3	Jul-Sep
McClure Pass	52.0	48.8	72.0	24 May	68.4	10 Jul	11.8	May-Jul
Ripple Cr Pass	54.9	54.7	76.7	8 Aug	72.0	18 Jul	16.3	Jul-Sep
Grand Mesa	No data							
Norwood	50.8	37.1	69.2	22 Jul	67.4	7 Aug	12.1	May-Jul
Douglas Pass	52.8	52.6	77.2	7 Aug	71.6	25 Jul	16.7	Jul-Sep
Snowbird	56.3	53.5	88.2	8 Aug	81.8	25 Jul	25.3**	Jul-Sep
Dark Canyon	No data							
Ruby Guard	51.0	44.2	88.1	8 Aug	75.4	15 Aug	16.7	Jul-Sep

Table 2: Summary statistics for all 2021 Sites. "Average O_3" is the mean of ozone readings between 8 a.m.-8 p.m. (Daytime) and 8 p.m.-8 a.m. (Overnight) for the entire growing season (April-September). "Daily 8-hour O_3" reports the days on which the highest and 4th-highest 8-hour averages were recorded (see text for further explanation). Values in red (over 70 ppb) are contributory to NAAQS exceedance.

*indicates site where missing data precluded complete assessment; actual peak may not have been observed. Deployment dates listed in Table 1.
**Value reflective of potential impact of long-term vegetation exposure; see text.

III. Discussion:

See summary statistics in Table 2 above.

Wildland fire, a major source of ozone precursor production in 2020, was less of a factor in 2021. Total acreage burned nationwide fell from 4.1 million hectares to 2.9M ha. While still substantial, the geography and meteorological conditions of fire in 2021 combined to lessen the impact on air quality in the R2/R4 footprint. However, the ongoing western US drought conditions and continued upward trend in daytime air temperature provided supportive conditions for converting precursors to surface ozone.

A number of broad trends in the 2021 data can be identified. Commonly, the high-elevation sites on the network record peak ozone levels in springtime, when the upper atmosphere is active and weather fronts regularly bring stratospheric ozone down to the surface. However, in 2021, nearly all of the sites experienced peak ozone levels in summertime, from mid-July through early September.

Relatively stagnant meteorological conditions and a period of hot, dry weather influenced the western US in midsummer, and most sites experienced an extended period of elevated ozone from about July 9th through the middle of August. This event was especially emphatic in the network's eastern and northern sites. Stations on the Pawnee National Grassland were strongly affected in late July, recording some of their highest readings ever and producing unprecedented exposure metrics. From May through September, exposure at both Briggsdale and Pawnee Buttes were above the hazard threshold for sensitive species. The elevated midsummer readings were evident in the data as far southwest as Norwood.

A second high-amplitude event in early September also affected many sites. Though relatively short-lived, this event is notable because it occurred so late in the summer, at a time when the lower sun angle usually results in less surface ozone production.

Sites farther south and west were less impacted in 2021. The CASTNet sites at Mesa Verde, Canyonlands and Great Basin National Parks, and the RMRS site in northeastern Nevada, had readings close to historical averages, and the long-duration events elsewhere were not as evident at these remote sites.

The sustained nature of the midsummer ozone event posed significant hazard to sensitive vegetation species. Besides the Pawnee National Grassland, areas of particular concern are the Colorado Front Range and the Uintah Basin and Wasatch Front in Utah, where 3-month W126 values exceeded the threshold of 17 ppm-hr proposed by USEPA as a secondary standard. Note that a recent research review (Grulke and Heath 2020) indicates that vegetation, especially herbaceous plants, may experience metabolic difficulties due to high ozone exposure, even in the absence of visible tissue necrosis. Another recent publication on trees (Lee and others 2022) continues a line of research that identifies ponderosa pine and quaking aspen as species particularly sensitive to elevated ozone.

The USEPA design value (three-year average of the fourth-highest 8-hour daily average or MDA8; Table 3 below) is above the ozone NAAQS of 70 ppb at seven sites, only three of which (RMNP CASTNet, Briggsdale and Snowbird) are within current USEPA nonattainment areas. Two other sites, Deadman Pass in Larimer County, Colorado and Little

Mountain in Uintah County, Utah, are just outside of nonattainment area boundaries but are within counties partially included in the designation. Goliath Peak and Kenosha Pass, Colorado, are in counties not presently designated for nonattainment.

Site	2019	2020	2021	2019-2021 Avg
Year-Round Sites				
Pawnee Buttes	66.7	62.8	79.5	69.7
Briggsdale	72.8	67.1	78.2	72.7
Kenosha Pass	69.2	71.8	76.5	72.5
Sunlight Mtn	69.9	64.7	68.7	67.8
Little Mtn	71.6	68.4	76.7	72.2
Hebron Slough			71.6	
Centennial CASTNet	65.0	61.6	72.1	66.2
RMNP CASTNet	65.6	67.8	77.8	70.4
Gothic CASTNet	66.4	63.4	65.0	64.9
Dinosaur CASTNet	70.8	61.0	68.1	66.6
Shamrock	59.6	62.3	66.4	62.8
Mesa Verde CASTNet	65.1	64.6	67.8	65.8
Canyonlands CASTNet		61.5	69.1	
GBNP CASTNet	66.5	66.3	68.6	67.1
Seasonal Sites				
Deadman Pass	63.6	67.9	83.3	71.6
Goliath Pk	69.7	72.9	84.1	75.6
Trout Cr Pass	65.9	65.6	72.8	68.1
Kremmling	60.8	65.4	67.7	64.6
McClure Pass	67.2	63.9	68.4	66.5
Ripple Cr Pass	55.4	64.0	72.0	63.8
Grand Mesa	65.5	62.6		
Norwood	63.2	67.8	67.4	66.1
Douglas Pass	63.4	62.2	71.6	65.7
Snowbird	69.3	70.6	81.8	73.9
Dark Canyon	57.5	64.4		
Ruby Guard	60.4	61.8	75.4	65.9

Table 3. Fourth-maximum daily values (MDA8) and three-year averages. Red indicates exceedance of NAAQS.

IV. Funding.

Beginning in FY21, the new USFS budget process prohibited transfer of funds between units for salary, travel and mileage. Unlike years past, when Region 2 provided the majority of funding for ozone work, in FY21 all salary, travel and mileage costs were borne by RMRS. Region 2, and the Arapaho-Roosevelt and Ashley NFs were still able to contribute funds for supplies, repairs, and replacement parts. A summary of funding is provided in Tables 5 and 6 below:

Source	Jobcode	Allocated, FY21	Expended	Balance, end FY21
Region 2	NFMG16	4000.00	3810.36	189.64
ARNF	NFVW10	6000.00	6000.00	0.00
Ashley NF	NFVW01	500.00	313.47	186.53
Total		10500.00	10123.83	376.17

Table 5. Non-RMRS funding sources, expenditures and remaining balance, ozone data collection and analysis, FY21

Item	Amount	Percentage of Total
Salary	30000.00	64%
Travel	2852.33	6%
Vehicle Mileage	4500.00	10%
Parts/Equipment	5416.09	12%
Contract Repairs	3744.30	8%
Contract Services	0.00	0%

Table 6. Expense categories and percentage of total expenditures, FY21

The salary line approximates eight pay periods, the time needed to conduct field work, complete data QC and analyses, and write this report.

V. Acknowledgments:

RMRS personnel are grateful for the assistance of site operators Helen Kempenich and Andrea Holland (retiree volunteers), Chris Plunkett and Kevin Faucher (Ashley NF), and David Eiriksson (NRCS-Salt Lake City). Their efforts result in increased efficiency of this project and considerable cost savings. RMRS also thanks Clyde Sharp and Bret Harkwell, Air Quality Division, CDPHE, for their efforts to conduct audits at many of the RMRS sites.

VI. Literature Cited:

Grulke, N. and R.L. Heath. 2020. Ozone effects on plants in natural ecosystems. Plant Biology 22:12-37.

Lee, H., C. Andersen, P. Beedlow, D. Tingey, S. Koike, J. Dubois, S.D. Kaylor, K. Novak, R.B. Rice, H. Neufeld, and J. Herrick. 2022. Ozone exposure-response relationships parametrized for sixteen tree species with varying sensitivity in the United States. Atmospheric Environment 284.

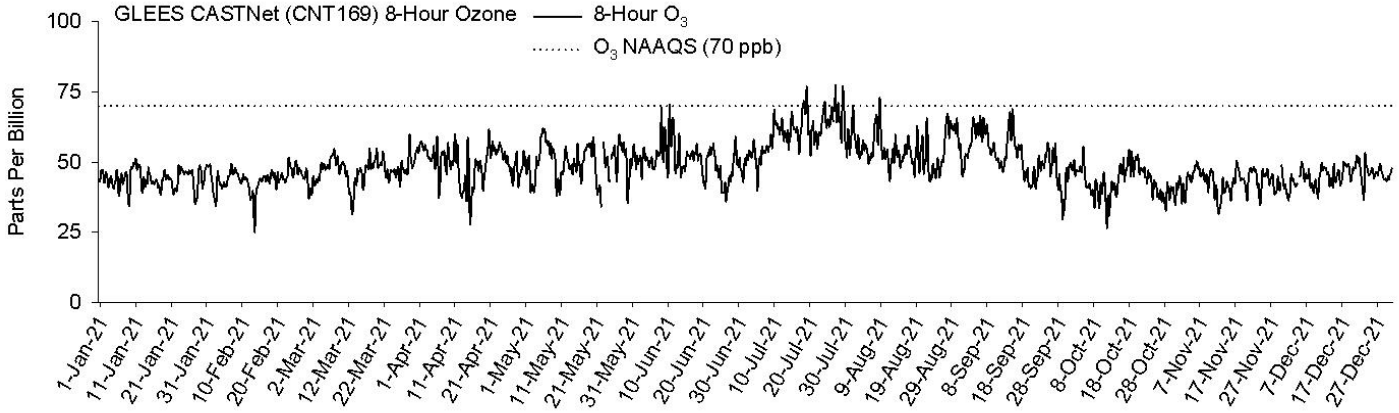
USEPA, 2019. News release dated December 19th, 2019: https://www.epa.gov/newsreleases/epa-reclassifies-denver-area-serious-nonattainment-ozone. Accessed 1 December 2022.

USEPA, 2021. Nonattainment and Unclassifiable Area Designations for the 2015 Ozone Standards -- April 30, 2018: Response to Remand Updates Shown in Red – November 2021. https://www.epa.gov/system/files/documents/2021-11/summar1.doc_0.pdf, accessed 1 December 2022.

Appendix A. Individual Site Data and Discussion.

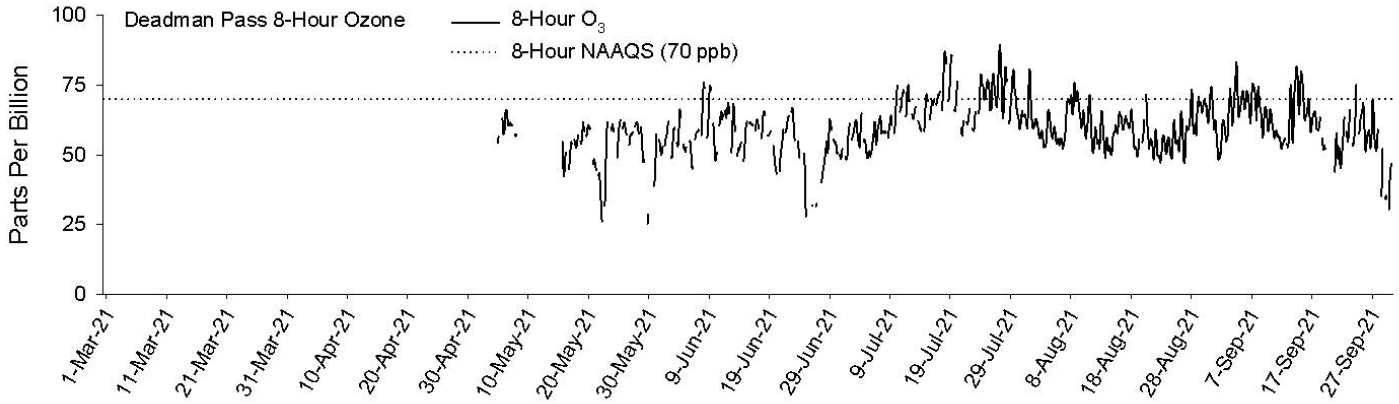
Region 2 Sites.

1. Centennial CASTNet. This high-elevation site in southeast Wyoming normally experiences steady, moderate ambient ozone, averaging about 48.5 ppb. Data from 2021 indicate only a 1 ppb increase over 2020, but a series of elevated ozone events occurred from mid-July through mid-August, where surface ozone averaged 61.5 ppb for over a month. Ozone remained significantly above historical patterns well into September. Peak 3-month W126 of 16.1 ppm-hr was recorded in the July-September frame, third-highest since at least 2007.



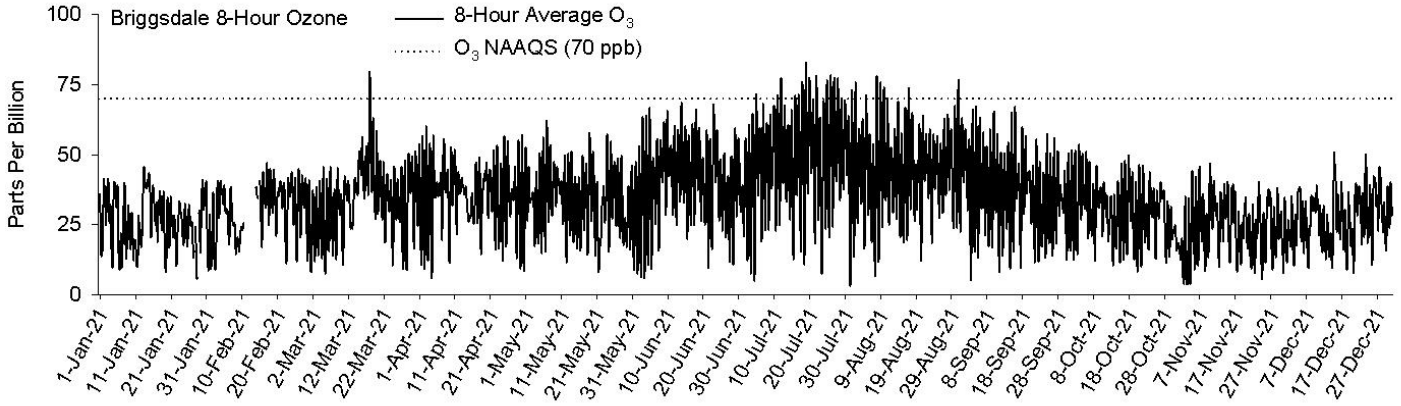
Highest 1-hour readings occurred in mid-June, but the midsummer events also saw an unusually high 4th maximum MDA8 for this site, at 72.1 ppb on August 9th. This places Centennial's three-year design value average at 66.2 ppb.

2. Deadman Pass. The midsummer ozone event was emphatic at this site, with a one-month average of 65 ppb; this figure is skewed slightly higher due to the lack of overnight ozone data early in the period. Additional periods of elevated ozone occurred in early September. A peak reading of 98.9 ppb on July 27th is the highest recorded at the site and one of the highest seen that was not heavily influenced by wildfire emissions. Peak 4th-max MDA8 of 83.3 ppb was second only to Goliath Peak in 2021. W126 (25.3 ppm-hr, July-September) remains at a level potentially hazardous to vegetation.



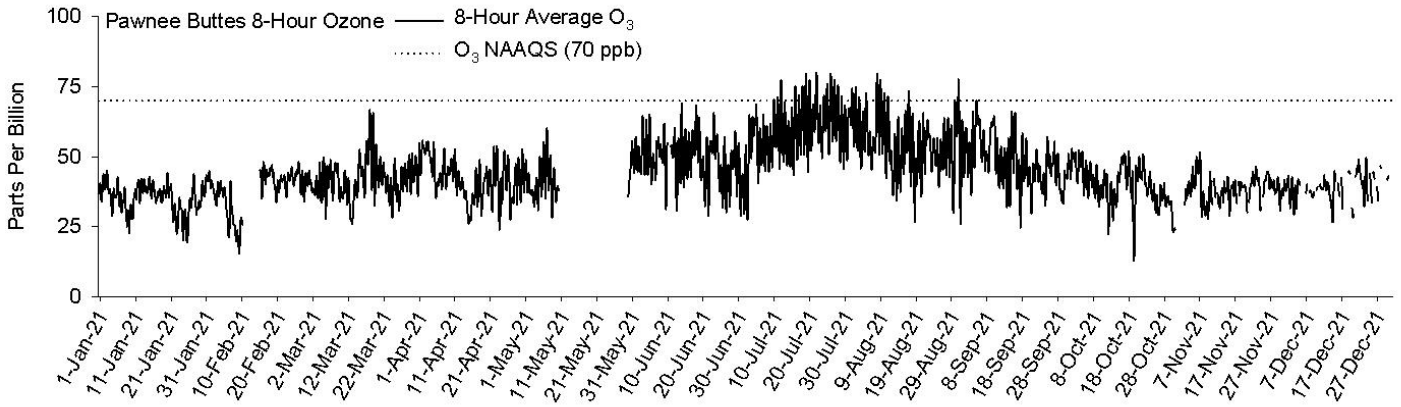
Despite missing some spring and early-summer data in the previous two years, the design value at Deadman (71.6 ppb, 2019-2021) is over the NAAQS. Although the site is in Larimer County, it is not within the boundary of the EPA's Denver/North Metro nonattainment area.

3. Briggsdale. The Pawnee National Grassland experienced an event on March 18th where ozone briefly peaked at nearly 100 ppb. This event produced the second-highest MDA8 (79.6 ppb) of the year, but its impact was limited due to the event's very short (7 hours) duration. More significant impact occurred in mid to late summer when daytime readings averaged 63.4 ppb for the period July 13th – August 17th. This 36-day period also included Briggsdale's maximum and 4th-maximum MDA8 values (83.0 and 78.2 ppb, respectively).



Although yearly average daytime ozone was only 1.3 ppb higher than in 2020, peak W126 at 24.6 ppm-hr (June-August) was the highest on record (for comparison, 15.7 in 2020, 13.3 average since 2011). Ozone appears to be steadily increasing here, with the current design value at 72.7 ppb, well over the ozone NAAQS.

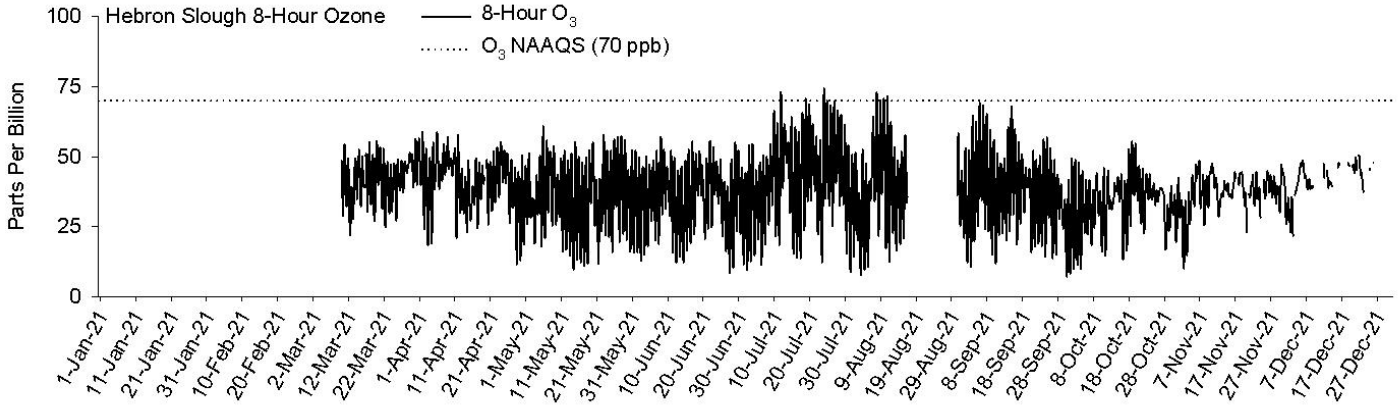
4. Pawnee Buttes. The brief spring-equinox ozone peak was much lower amplitude at this eastern PNG site. This event is not easily explained by passage of synoptic weather systems or an obvious stratospheric folding event; it was noted only at the two PNG sites. On the state's O3 monitoring network, the Fort Collins-West and Platteville stations, west and south of the PNG, registered unusually high readings (72-75 ppb) on the afternoon of March 18th. Ozone remained relatively modest until midsummer where the extended elevated ozone event had even greater impact than at Briggsdale. Unlike its eastern PNG counterpart, average daytime ozone was substantially greater than in 2020 (47.9 ppb versus 44.3), and the maximum MDA8 values (80.0 and 79.5 max and 4th-max, respectively) reflect this.



Maximum 3-month W126 at 27.9 ppm-hr (June-August) was the highest on the network for 2021, and also the highest yet recorded at Pawnee Buttes since the inception of monitoring in 2011. This exposure metric is in the range of potential vegetation damage at both Pawnee Buttes and Briggsdale.

5. Hebron Slough. An unknown analyzer malfunction caused the loss of data during the last two weeks of August; otherwise this newest site on the network, about 35 km south of Walden, CO, performed well. Like the other eastern

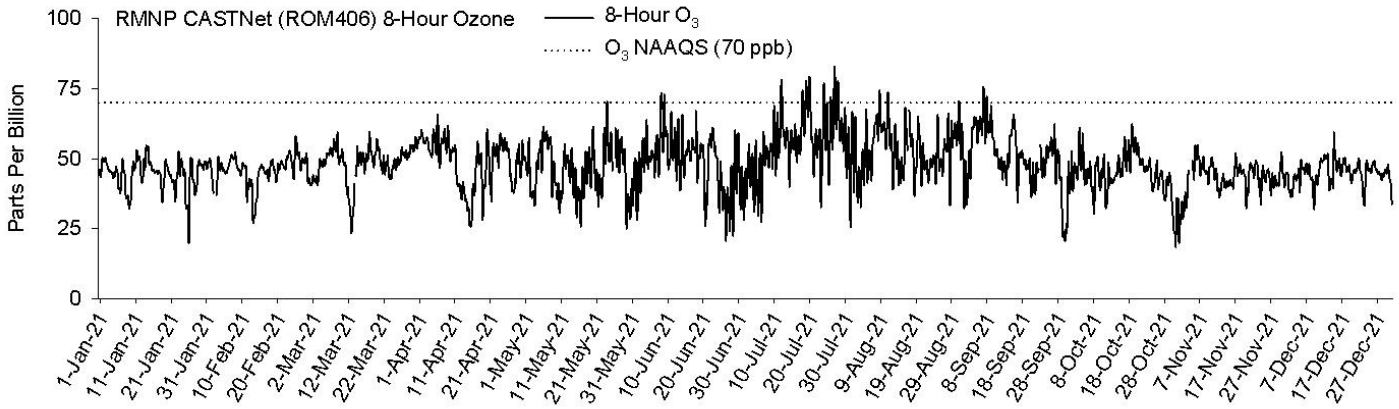
Colorado sites, ozone peaked here in midsummer in a series of elevated ozone events that saw readings well over 70 ppb. The highest MDA8 value (74.4 ppb) was recorded on July 24th, and the fourth-maximum occurred on August 11th (71.6 ppb). This was the site's first year of operation and the NAAQS design value will not be available until 2023.



Exposure metric W126 peak was 10.4 ppm-hr, but this was for the May-July period. The analyzer malfunction prevented assessment of the July-September period which likely would have seen a higher number.

Significant ozone titration (ozone being broken down into O_2) occurs at this site, very likely due to the presence of significant NO_X. A site with little NO_X impact will exhibit little variation in ozone overnight. For example, at Sunlight Mountain the day/night differential is only 0.2 ppb; at Hebron Slough, NO_X breaks down ozone overnight when there is no sunlight to re-generate ozone. The day/night differential at Hebron Slough is 16.9 ppb.

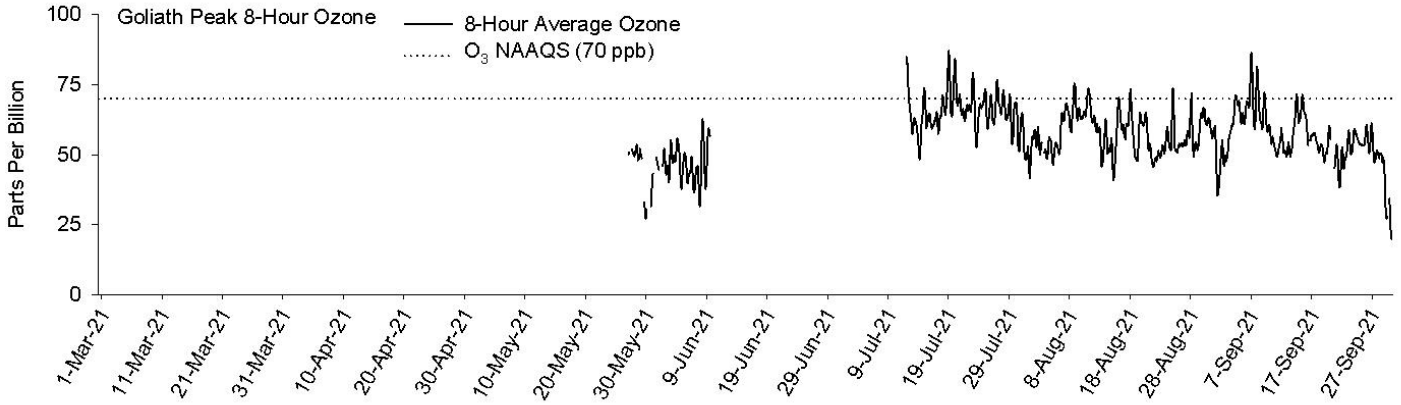
6. RMNP CASTNet. Much like other Front Range sites, the CASTNet site at Rocky Mountain National Park recorded minor events in late spring, and then experienced a series of high-impact events from mid-July through mid-August. An early-September event seen at the Pawnee National Grassland sites was also evident at RMNP. MDA8 peaked at 83.0 ppb, and fourth-max MDA8 was 77.8 ppb on July 19th. This value pushes the 2019-2021 design value to 70.4 ppb, which exceeds the ozone NAAQS.



Vegetation exposure to ozone was significant at RMNP, with 3-month W126 exceeding 17 ppm-hr from May through September. This is the first year since 2012 that this site has recorded levels potentially hazardous to vegetation. The potential for ozone damage very likely extends into the Indian Peaks and Comanche Peak Wilderness Areas.

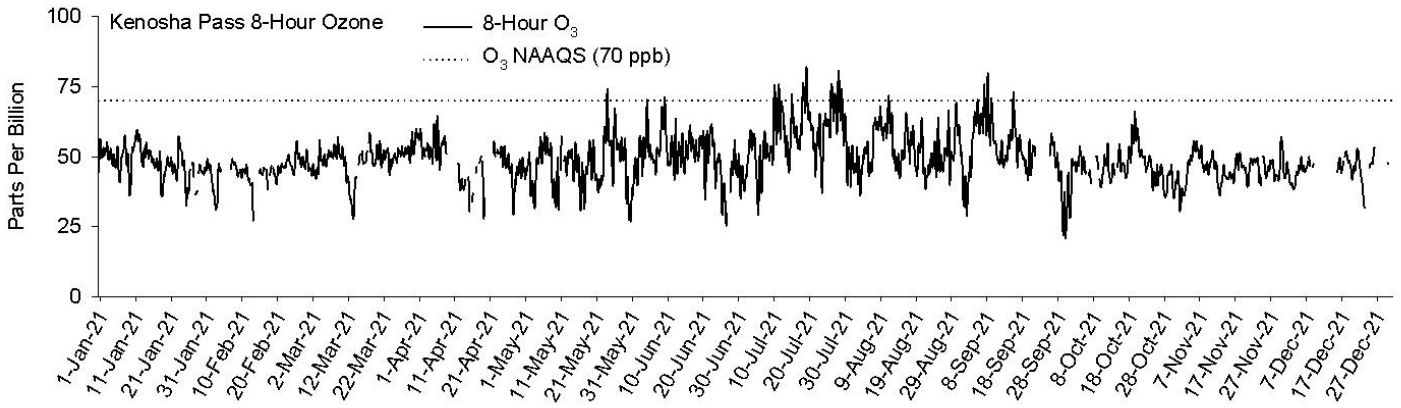
7. Goliath Peak. Sample air pump failure prevented data collection for most of June and early July at Goliath. The long-duration event that affected other Front Range sites in mid-July also was in evidence at Goliath. Max and 4th-max MDA8

both occurred during this event (89.5 and 83.3 ppb, respectively). The design value (75.6 ppb) remains well over the ozone NAAQS.



A full assessment of exposure metrics was not possible here in 2021 due to the missing data. However, W126 peaked at other Front Range sites in the July-September frame, and peak observed W126 (13.1 ppm-hr, July-September) at Goliath was likely the highest experienced at the site. Had early-July data been available, W126 would have been measured at about 15 ppm-hr.

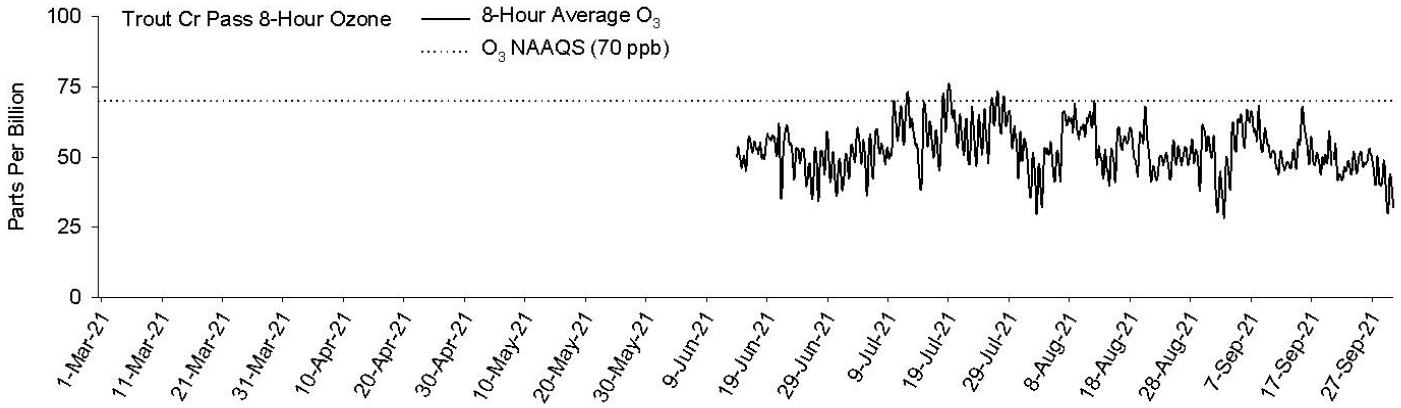
8. Kenosha Pass. The annual trace and notable events at Kenosha followed the same pattern as other montane Front Range sites; high-elevation ozone was remarkably homogeneous in this region in 2021. Minor peaks occurred in late spring, with significant longer-duration events in the mid-July to mid-August period and also early September. As at RMNP, the mid-July events produced the highest regulatory values (max and 4th-max MDA8 of 82.2 and 76.5 ppb, respectively). Kenosha's design value for 2019-2021, at 72.5 ppb, remains well over the ozone NAAQS.



In contrast, W126 remains at a (relatively) benign 15.4 ppm-hr (July-September). This continues a longer-term trend of 3-month W126 values below the impact threshold of 17 ppm-hr. Ozone at Kenosha has not exceeded this value since 2010.

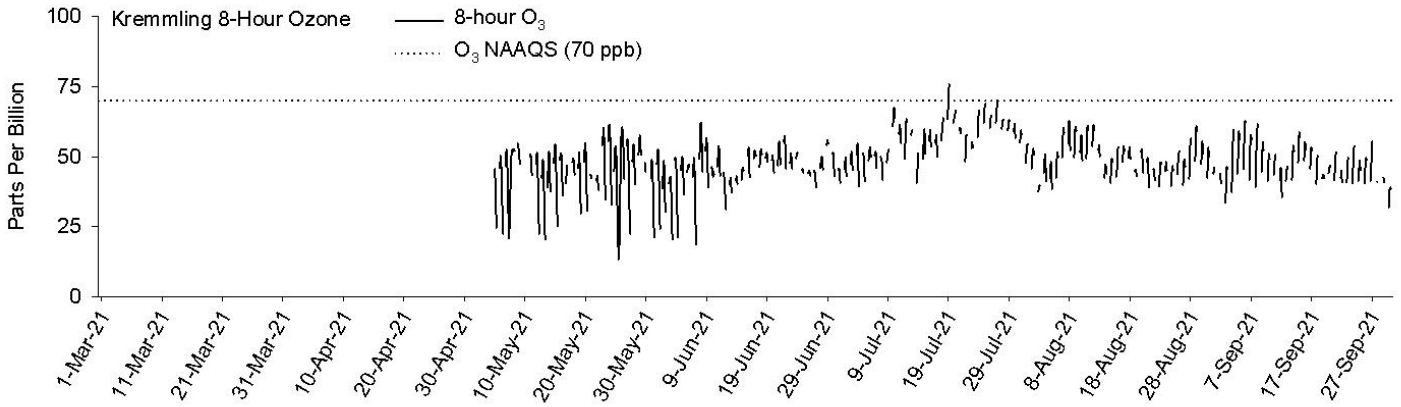
9. Trout Creek Pass. This site and Centennial are the only Front Range-proximate sites to remain well below the ozone NAAQS. Trout Creek's 2019-2021 design value stands at 68.1 ppb. The site experienced some elevated ozone in mid-July,

but ozone remained below 70 ppb through the remainder of the monitoring season.



Vegetation impact was higher this year (three-month W126 of 16.2 ppm-hr, July-September) than in the past several years, but remains relatively modest.

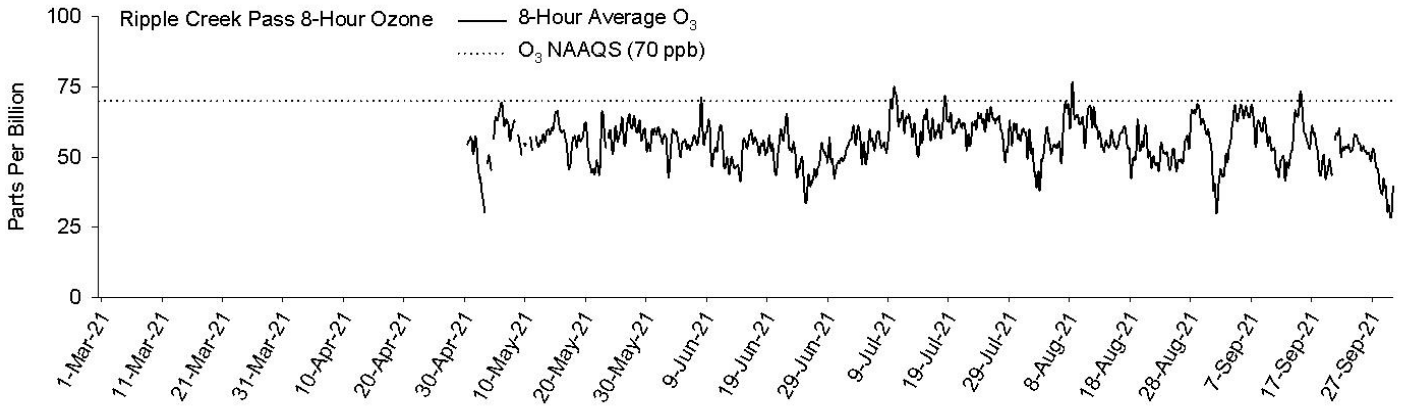
10. Kremmling. Daytime ambient ozone values at Kremmling remained at levels typical of most years on record. MDA8 values exceeded 70 ppb on only one day in the 2021 monitoring season (75.8 ppb, July 19th), and the fourth-maximum MDA8 (on July 10th) was 67.7 ppb, well below the NAAQS. The 2019-2021 design value at the site of 64.6 ppb remains among the lowest on the network. Power supply problems at the site resulted in a loss of most overnight data.



Exposure (W126 of 10.3 ppm-hr, July-September) remains below vegetation hazard threshold.

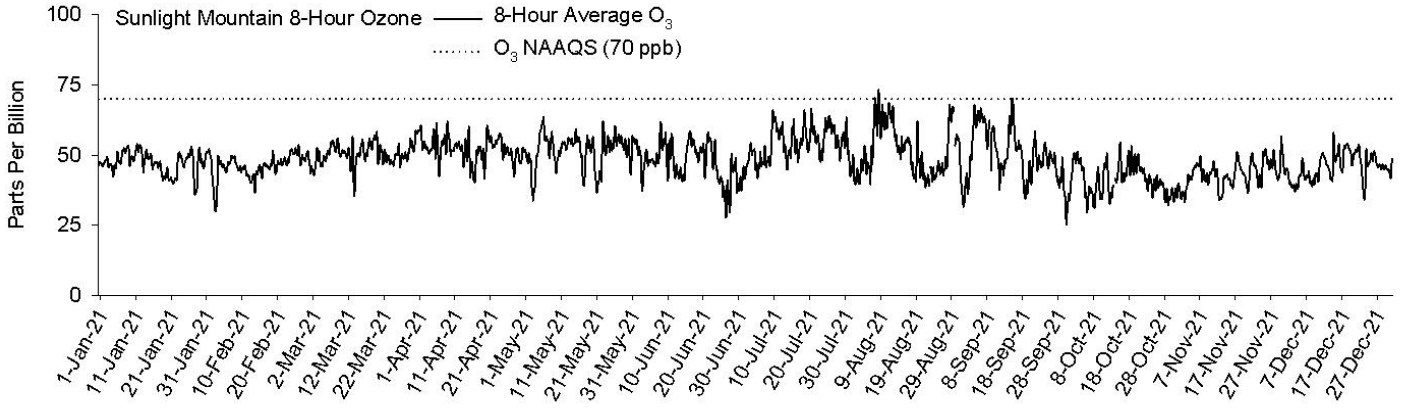
11. Ripple Creek Pass. This site, near the northern boundary of the Flat Tops Wilderness, experienced some brief events of elevated ozone in spring, and also appears to have seen lower-amplitude versions of the events noted on the Front Range sites. The fourth-maximum MDA8 was recorded during the early-summer event (72.0 ppb, July 18th), but the duration of other events was too short to cause 8-hour spikes. Despite this year's unusually high fourth-max reading, the

three year design value of 63.8 ppb remains well below the NAAQS and is the lowest observed on the network.



The elevated ozone in July did produce one of the site's highest exposure indices (W126 of 16.3 ppm-hr, July-September), exceeded only in 2018. Consecutive 3-month W126 values from May through September (16.1, 15.4, and 16.3 ppm-hr), indicate continuous moderate ozone exposure, which may be harmful to especially sensitive species.

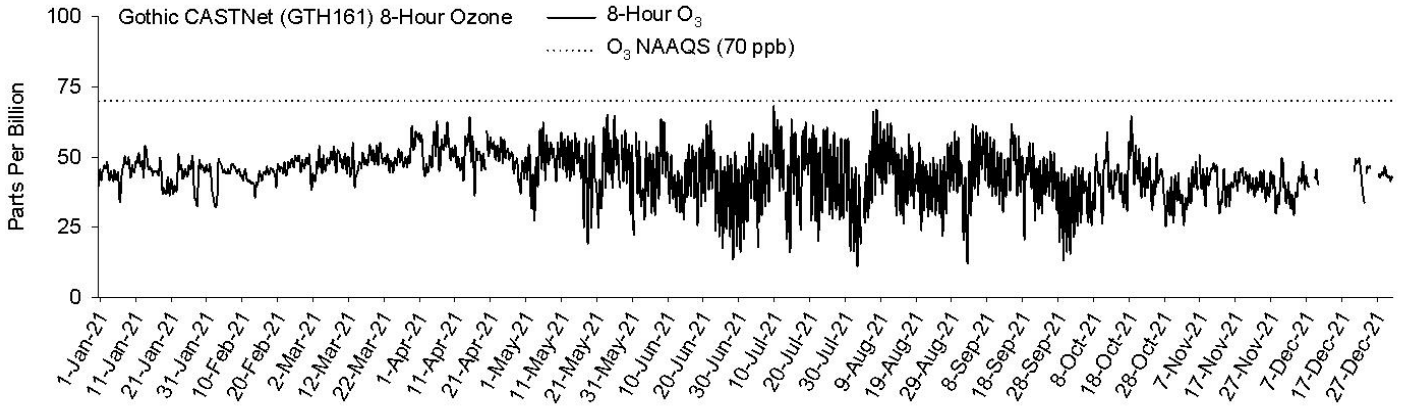
12. Sunlight Mountain. Consistent, modest ozone readings were again the prevailing theme at Sunlight in 2021. The mid-July even was mostly absent at this site, with 8-hour readings exceeding 70 ppb only in mid-August. This period produced the maximum and fourth-maximum MDA8 values (73.3 ppb, August 8th; and 68.7 ppb, August 11th, respectively). The 2019-2021 design value of 67.8 remains below NAAQS.



Sunlight was the only site on the network to record a single-digit 3-month W126 value in 2021 (9.6 ppm-hr, July-September). This value is below the site's historical average. The site has not experienced hazardous exposure since 2012.

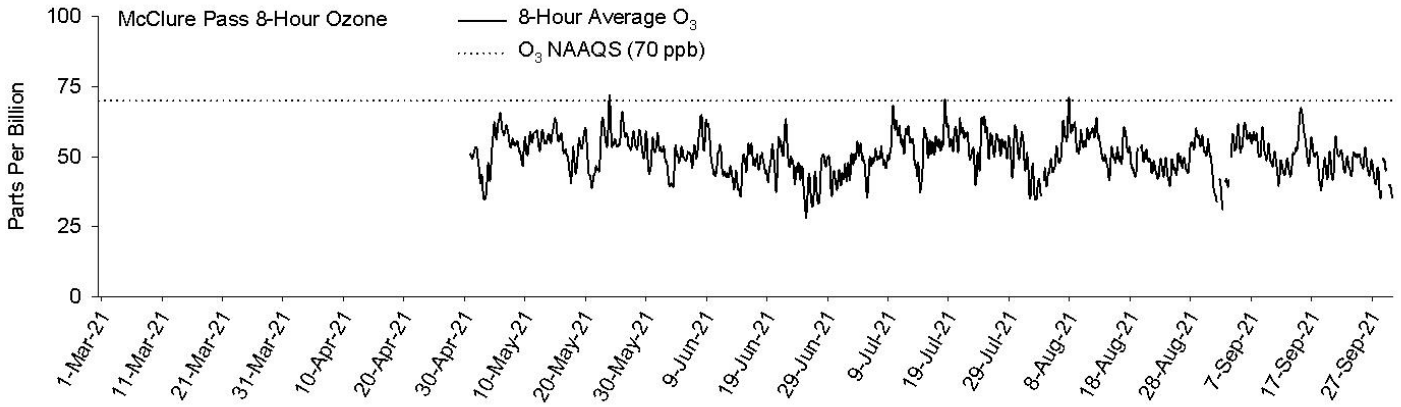
13. Gothic CASTNet. This eastern Elk Range site was one of only three sites whose maximum MDA8 did not exceed 70 ppb in 2021 (68.1 ppb, July 10th). The 2019-2021 design value of 64.9 ppb is among the network's lowest figures. An unusual feature of Gothic's data is the considerable overnight ozone titration during spring and summer. The source of the chemistry causing this is not known, but could be because of seasonal changes in wind patterns. Zonal (westerly) winds predominate in late autumn through early spring. However, winds have a more southerly vector during the

warmer months, directing NO_X toward the site from the towns of Crested Butte and Mt. Crested Butte.



Vegetation exposure remains moderate (peak of 10.8 ppm-hr, May-July) at Gothic, continuing the long-term trend.

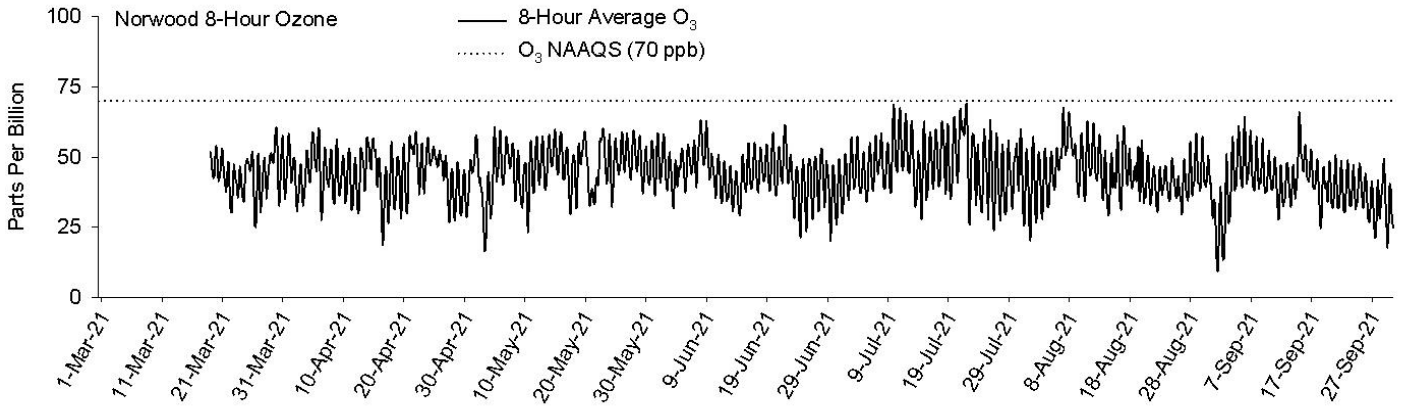
14. McClure Pass. Perched on the remote divide between the Gunnison and Roaring Fork drainages near the Raggeds Wilderness, McClure Pass continued the recent trend of relatively benign surface ozone. Several minor events occurred during the monitoring season, with the maximum MDA8 value recorded (72.0 ppb) on May 24th. The mid-July event was muted here but did result in the 4th-max MDA8 of 68.4 ppb, on July 10th. Design value at this site of 66.5 ppb remains well below NAAQS.



No concern for vegetation exposure is current evident at McClure, with 3-month W126 at 11.8 ppm-hr (May-July). This value is similar to those recorded since 2018.

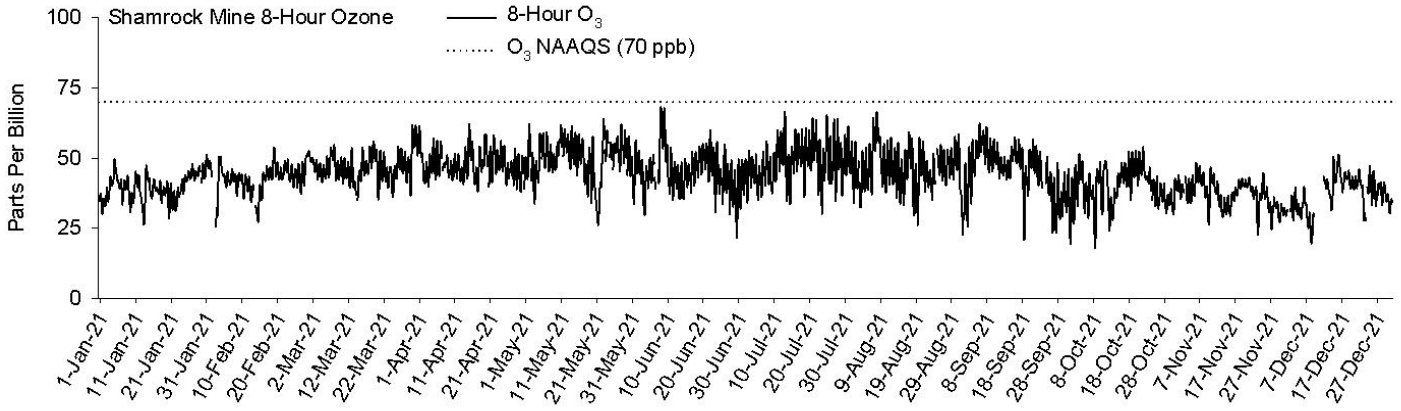
15. Norwood. Low wildfire activity and the remote location puts Norwood again among the network's cleaner sites. No MDA8 values exceeded 70 ppb in 2021 (max 69.2 ppb on July 22nd, 4th-max 67.4 ppb on August 7th). The design value for

2019-2021 remained well below NAAQS at 66.1 ppb.



Vegetation exposure remains low at Norwood, with W126 peaking in May-July at 12.1 ppm-hr. The earlier peak is in contrast to most sites this year where peak values were recorded later in the monitoring season.

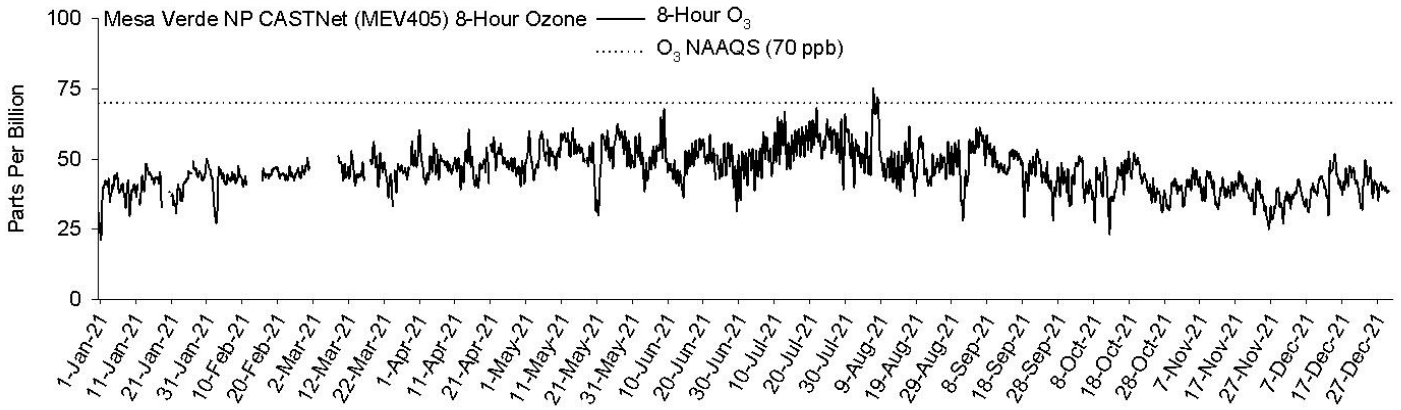
16. Shamrock. Like most of the Colorado west slope sites, Shamrock's location near the southern boundary of the Weiminuche Wilderness isolates the site from most ozone precursor sources. Ozone at this contractor-operated site was very similar to that observed at Norwood: only a few short-duration events approached 70 ppb. The mid-July event did not produce either the maximum or fourth-maximum MDA8 (68.3 ppb, June 8th; 66.4 ppb, August 8th, respectively). The three-year design value remains the lowest on the network at 63.8 ppb.



Three-month W126 maximum was 10.8 ppm-hr (July September); no vegetation hazard is current suspected at the site.

17. Mesa Verde National Park CASTNet. Springtime produced only one significant ozone event at Mesa Verde, with eight-hour averages approaching 70 ppb in mid-June. This event also produced the regulatory MDA8 value of 67.8 ppb on June 9th. The highest MDA8 was 75.3 ppb on August 7th. The three-year design value remains below the NAAQS at

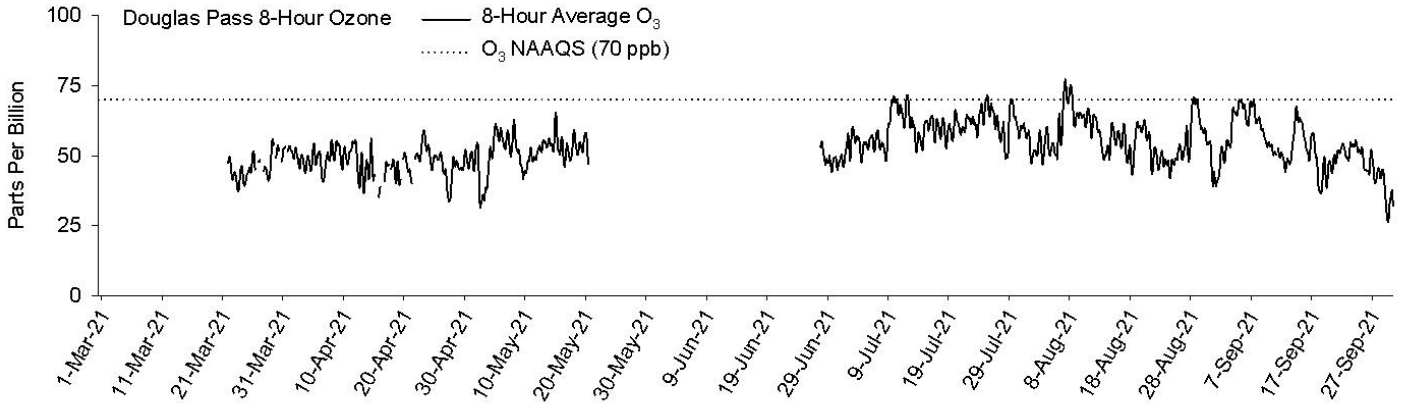
67.8 ppb.



The early-August ozone event did not significantly impact vegetation exposure at Mesa Verde. Maximum 3-month W126 was instead recorded in May to July, at 13.1 ppm-hr. No hazard is currently present.

18. Grand Mesa.

19. Douglas Pass. An undiagnosed analyzer malfunction occurred at Douglas which prevented data collection from mid-May through late June. The operator was able to get the instrument running during a regular site visit. Despite this, data coverage likely included the season's peak events. MDA8 peaked at 77.2 ppb on August 7th, highlighting a one-week period where ozone averaged 64.8 ppb. Fourth-maximum MDA8 occurred earlier, at 71.6 ppb on July 25th. Depsite this year's higher 4th-max, the three year design value of 65.7 ppb remains below NAAQS.

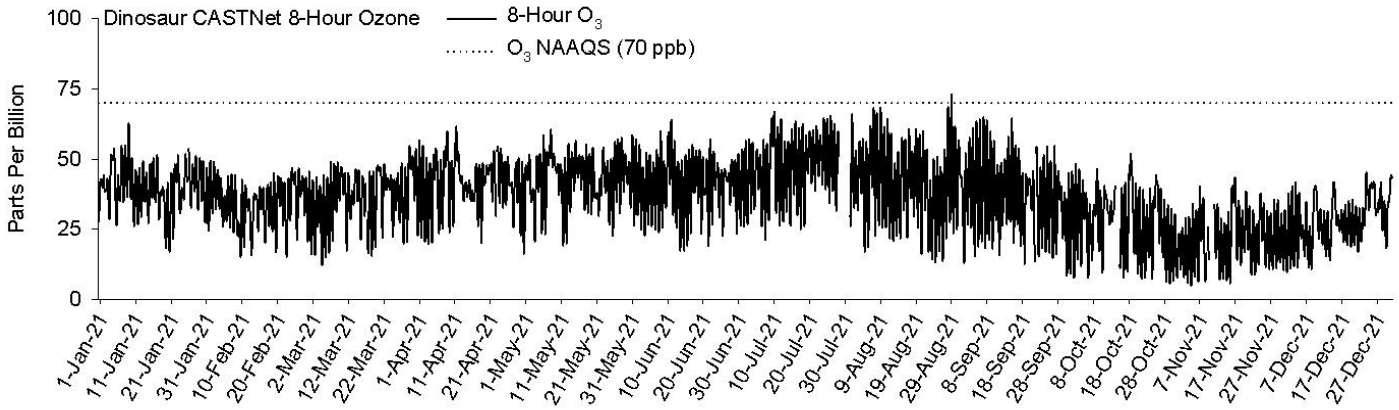


The August event pushed the three-month W126 for July-September to 16.7 ppm-hr, higher than usual for this site, and close to the 17 ppm-hr threshold commonly used for vegetation hazard. The site has not exceeded 17 ppm-hr since 2018.

Region 4 Sites.

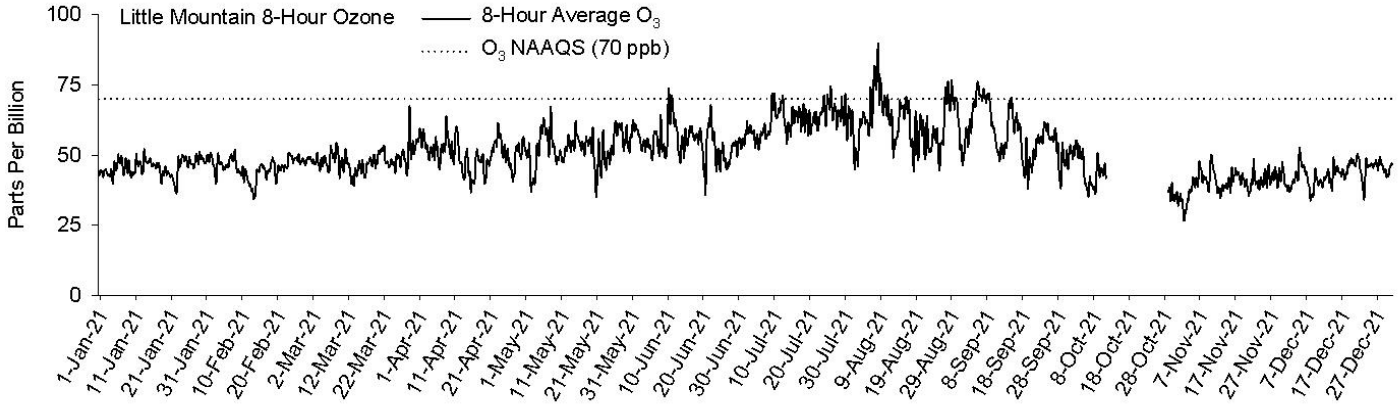
20. Dinosaur National Monument CASTNet. The northwesternmost site in Colorado was once ground-zero for severe surface ozone pollution in the winter months during the height of oil and gas development in northeastern Utah. However, the site experienced its third consecutive year of benign conditions in 2021, with MDA8 peaking at 73.1 ppb on August 29th. The regulatory 4th-max MDA8 of 68.1 ppb was recorded on August 7th. No long-duration ozone events

occurred in 2021, and the high-amplitude midsummer events prevalent farther east were mostly absent here.



Peak 3-month W126 was 13.3 ppm-hr in 2021, below vegetation hazard threshold. Exposure has remained below hazard levels since at least 2018.

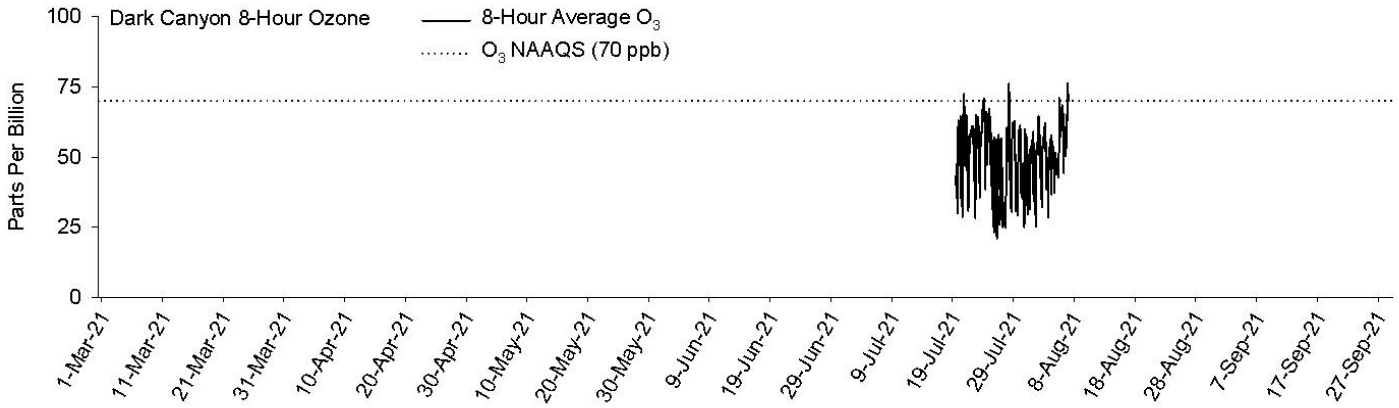
21. Little Mountain. A high-impact event occurred here August 6th-12th, a period of six days where ozone averaged 70.7 ppb. This event produced the site's 1st, 2nd and 3rd MDA8 maxima. The 4th max of 76.7 ppb occurred during another event on August 29th. Another event in early September also produced an extended period of elevated ozone. These events pushed Little Mountain's 2019-2021 design value to 72.2 ppb, well over the NAAQS. Several lower-impact events occurred throughout springtime and early summer.



The unusually sustained nature of elevated ozone at Little Mountain also elevated the site's 3-month W126 figure. At 26.1 ppm-hr, this is the second-highest exposure metric seen on the network in 2021, and the highest ever recorded at Little Mountain. In total, the site experienced 316 hours with ozone exceeding 70 ppb, nearly two weeks.

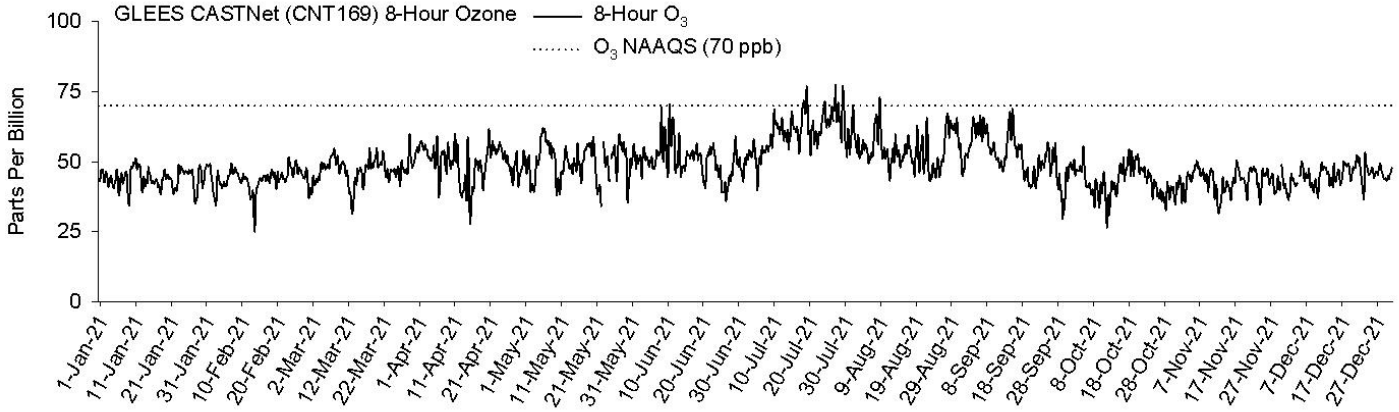
22. Dark Canyon. Heavy rain and impassable roads prevented access to the Dark Canyon site in autumn of 2021, so the instrumentation was left in place through the winter. Upon arrival in April of 2022, much of the previous year's data had been overwritten. And, regrettably, the analyzer experienced pump failure in August of 2021, limiting the 2021 dataset

to only three weeks.



No conclusions about ozone can be made for Dark Canyon in 2021.

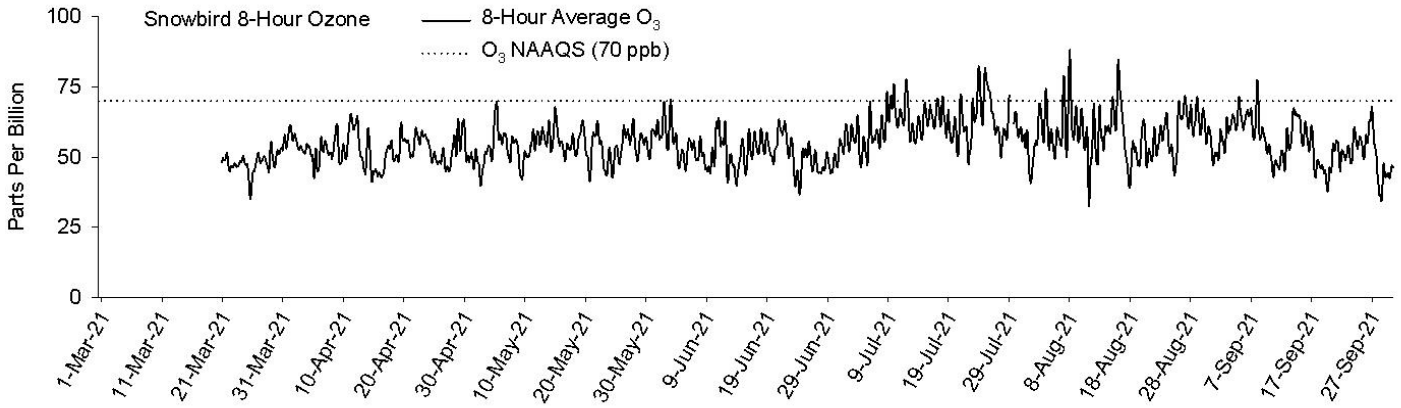
23. Canyonlands CASTNet. Late July to early August produced four short-duration events where ozone exceeded 70 ppb. Maximum MDA8 was recorded on August 8th, at 75.9 ppb, and 4th-maximum was 69.1 ppb three days later. A late spring event also produced levels in the upper 60s ppb, as did three longer-duration events in late summer. Canyonlands' design value remains under the NAAQS.



Vegetation hazard has historically been low at this remote desert site, and 2021 continues the pattern. W126 was 13.2 ppm-hr, up from the previous year but still below hazard threshold.

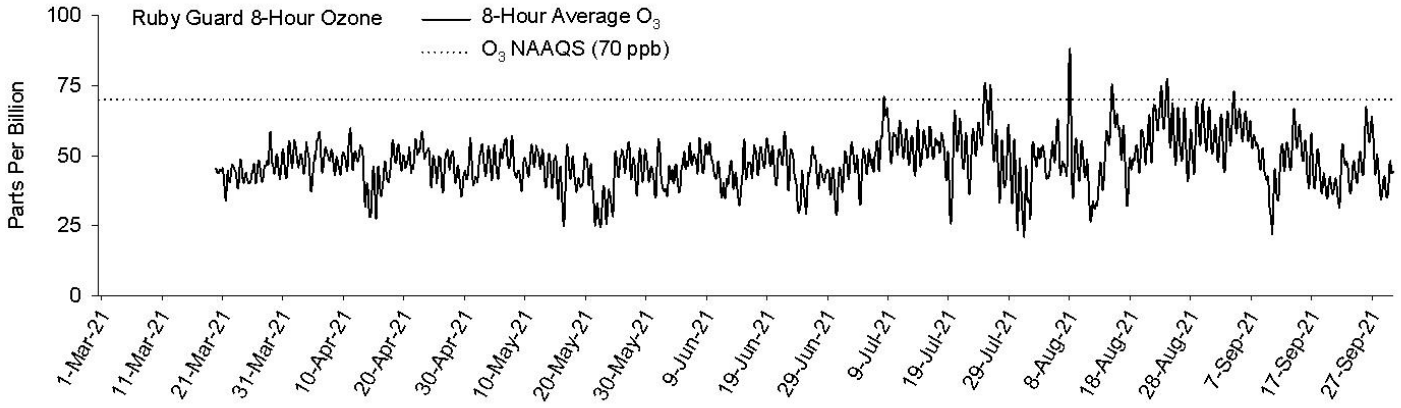
24. Snowbird. The mid-mountain location of this site, directly downwind and upslope from the greater Salt Lake City metro area, again produced some of the highest ozone readings on the network in 2021. The 39-day period July 9th-August 17th produced an average reading of 61.7 ppb, third-highest on the network for this period. Maximum MDA8 occurred on August 8th at 88.2 ppb, and the fourth-maximum was observed at 81.8 ppb on July 25th. The fourth-max figure puts the 2019-2021 design value at 73.9 ppb, well over the NAAQS. The Wasatch Front cities remain in one of

EPA's nonattainment areas.



Vegetation was again at risk at Snowbird, with 3-month W126 peaking at 25.3 ppb in the July-September frame. Several sensitive species (cutleaf coneflower, aspen, ponderosa pine) are common in the area and should be monitored for signs of ozone necrosis.

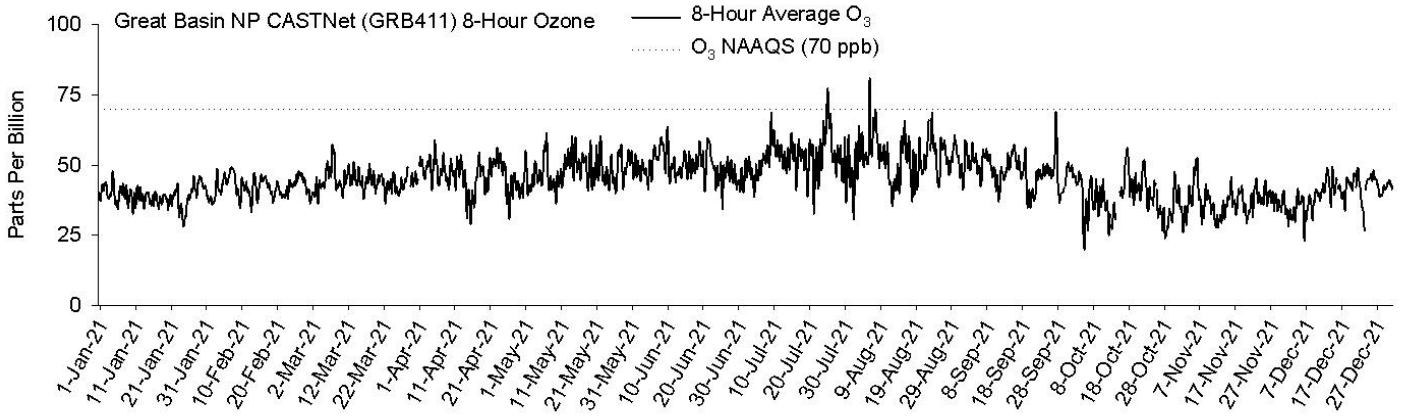
25. Ruby Guard. The network's westernmost site experienced an unusually high year for ozone. The early-summer events noted elsewhere were mostly absent at Ruby Guard, with only a modest late-July peak. However, a notable (but brief) spike occurred in early August, yielding the highest readings of the year (max MDA8 of 88.1 ppb on August 8th). Fourth maximum MDA8 was recorded during a lower-amplitude event (75.4 ppb, August 15th). Late August and the first few days of September also saw an extended period of high ozone. The 2019-2021 design value remains well below NAAQS at 65.9 ppb.



Peak 3-month W126 of 16.7 ppm-hr (July-September) was highest on record for this site, though the spotty nature of data collection in previous years makes comparisons difficult.

26. Great Basin National Park CASTNet. Excellent air quality remains the pattern at the Great Basin CASTNet facility in eastern Nevada. Only two events, both in early August, produced 8-hour averages exceeding 70 ppb. The late August and early September events noted at most other sites were absent at Great Basin. August 6th saw the year's highest MDA8 of 80.9 ppb, and fourth-max was recorded on July 9th. Three-year design value remains below ozone NAAQS at

67.1 ppb.



The 3-month W126 peak of 12.6 ppm-hr (June-August) is second highest on record but is well below vegetation hazard threshold.